



Original communication

Dental age assessment (DAA): A study of a Caucasian population at the 13 year threshold[☆]

Priya N. Chudasama BSc, MSc Postgraduate Student^{a,*}, Graham J. Roberts PhD, FDSRCS(Eng) Honorary Professor^b, Victoria S. Lucas PhD, BDS(Hons) Specialty Dentist^b

^a Cameron Centre for Forensic Medical Sciences, Barts and the London School of Medicine and Dentistry, Queen Mary University of London, London, United Kingdom

^b Department of Paediatric Dentistry, King's College Hospital, Camberwell, London SE5 9RS, United Kingdom

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ABSTRACT

The purpose of this study was to develop a Reference Data Set for Dental Age Assessment at the 13 year old threshold in Caucasian children.

Patients, Materials and Methods: The Reference Data Set comprised 5187 re-used Dental Panoramic Tomographs (DPTs) between the ages of 11–15 years, from both the Eastman Dental Hospital and King's College Dental Hospital archives. Tooth Development Stages were recorded for the left maxillary and mandibular teeth and all four permanent third molars (Demirjian et al., 1973, Demirjian 1978). A separate Study Sample of DPTs, comprising 50 males and 50 females aged between 10 and 16 years was collected to test the accuracy of the method. Summary Data was generated for the individual Tooth Development Stages which consisted of the number (n-tds), mean (x), standard deviation (sd) and the standard error (se). By using the mathematical techniques of meta-analysis, this data was used to estimate the age of each subject in the Study Sample. The estimated Dental Age derived was compared to the gold standard of Chronological Age.

Results: The mean difference between the Chronological Age and Dental Age was determined to be –0.1 years (–1.2 months) for males and 0.05 years (–0.6 months) for females.

Conclusion: Dental Age was reliably estimated at the 13 year threshold.

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1. Introduction

There has been an increase in cross border migration during the last decade as a result of armed conflicts, economics and European integration.¹ Many of the migrants have no birth records and as a result of this, age assessment for living individuals has become increasingly important for civil, criminal and forensic purposes.

This study has focused on the 13 year threshold. This is because sexual activity in individuals aged less than 13 years is statutory rape. The age of consent for sexual activity in the United Kingdom is 16 years, thus an age assessment for an individual thought to be younger than this may be requested by the police.²

Abbreviations: CA, Chronological Age; DA, Dental Age; DAA, Dental Age Assessment; DPT, Dental Panoramic Tomograph; x, Mean; n, Number of subjects; n-tds, Number of Tooth Development Stages; RDS, Reference Data Set; sd, Standard Deviation; se, Standard Error; TDS, Tooth Development Stage; TMTs, Tooth Morphology Types.

[☆] Postscript: The full reference data set for UK Caucasians can be obtained from graham.j.roberts@kcl.ac.uk.

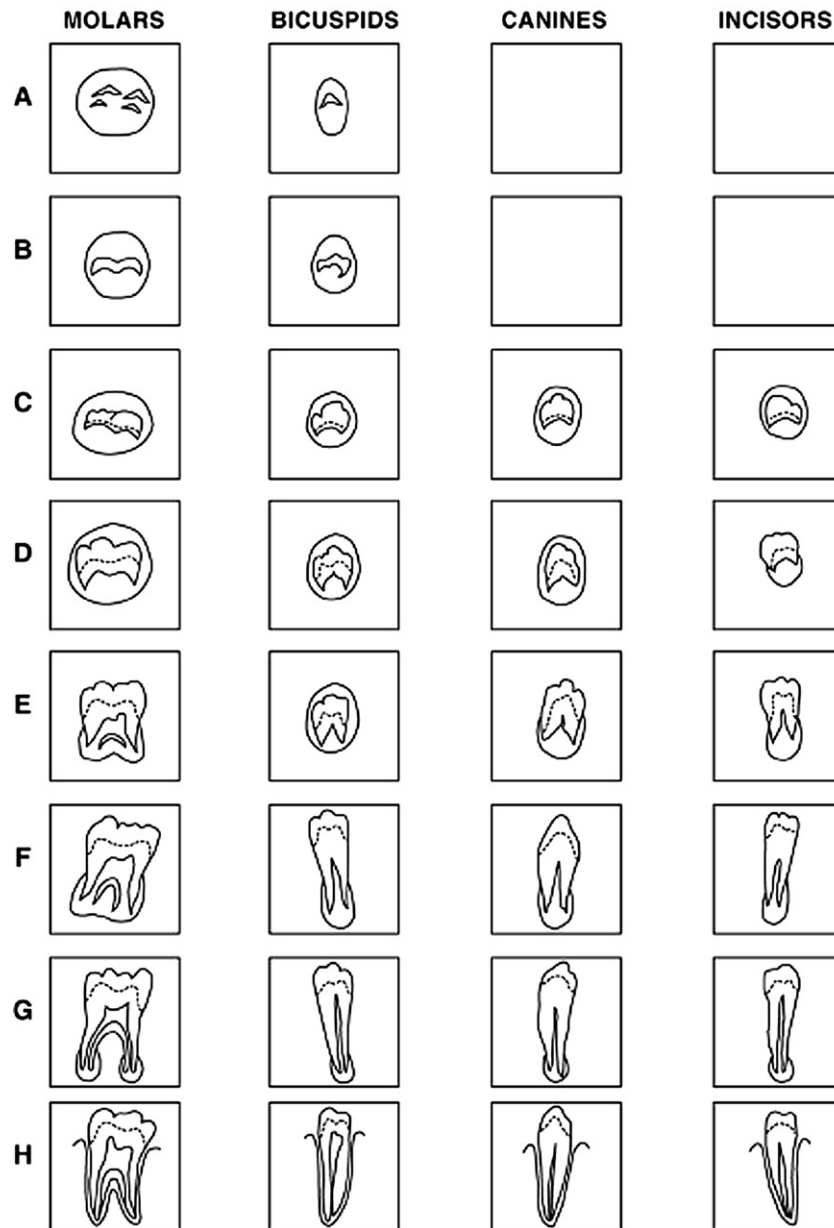
* Corresponding author. Tel.: +44 203 299 3375; fax: +44 203 299 4074.

E-mail address: priya_c@hotmail.co.uk (P.N. Chudasama).

The most widely practised methods of age assessment include sexual and psychological maturation. Anthropometric markers are also used, for example development and closure of the epiphyseal cartilages in the hand and wrist and the sterno – clavicular joint.³

The human dentition has been used for age assessment for many years.^{4–7} During the industrial revolution of the 19th Century, children were not permitted to work in factories unless the second permanent molars had emerged into the mouth.⁸ More recently, a number of schemes have been developed that use Tooth Development Stages (TDSs) for age assessment.^{5–7,9,10} One widely used method is the 8 stage system described by Demirjian which comprises discrete anatomical descriptions of tooth development stages (Fig. 1)^{9,11,12} These pictorial stages are clear and easy to identify, although the statistical computation is less useful because the original work was based on a specific population group of French – Canadian individuals. Nonetheless, this system has been applied and tested on a variety of populations.⁹

The introduction and widespread use of Dental Panoramic Tomographs (DPTs) has enabled the visualisation of TDSs by providing clear images of all 16 Tooth Morphology Types (TMTs). The advantages of using DPTs include simplicity of application,¹³



Schematic Representation for Eight Stages of Development

Fig. 1. Demirjian's 8 stage system.¹¹

rapid image generation, 50–80% reduction of radiation exposure,^{14,15} wider exposure latitude^{14,15} and patient comfort is increased.¹³

A recent method of calculating the Dental Age is based on the mathematical techniques of meta – analysis.¹⁶ This uses the mean and standard error of the summary data for all the TDSs of the maxillary and mandibular teeth on the left side, plus the two 3rd molars on the right side. The purpose of this work was to determine the accuracy of Dental Age Assessment compared with the gold standard of Chronological Age in children at the 13 year threshold.

2. Patients, materials and methods

This work was based on a Reference Data Set (RDS) derived from the DPTs of children and adolescents from the Eastman Dental Hospital and King's College Dental Hospital archives. Only those of

good diagnostic quality within the age range of 11 years–15 years were used. Each DPT was copied using a digital camera and stored on and subsequently assessed on a password protected computer.

2.1. Ethical approval

Ethical approval was granted by the King's College Hospital NHS Trust (Reference number: 06/Q0703/54). To ensure the data complied with the Data Protection Legislation, the study was registered by The Data Protection Officer of King's College Hospital NHS Trust.

2.2. Reproducibility

TDSs were recorded from 10 randomly selected DPTs from the database of subjects of known age¹¹ separate from the study, by two investigators to assess inter examiner reproducibility. This was

repeated one week later by the main investigator (PC) to assess intra examiner reproducibility. By using Cohen's Kappa scores, the level of agreement was determined based on the classification derived by Landis and Koch.¹⁷

2.3. Reference data set

This comprised re-used DPTs of British Caucasian children around the 13 year threshold retrieved from the Eastman Dental Institute and King's College Dental Hospital archives. Radiographs with poor quality images together with radiographs of children with systemic, syndromal, nutritional or medical conditions that could influence the rate of dental development were excluded. The date of birth of each subject was concealed for the TDS assessments. The Chronological Age of each subject was calculated within the database using the date of birth and the date of the DPT. Gender and ethnicity were also recorded.

2.4. Study sample

In order to test the accuracy of Dental Age Assessment for British Caucasian subjects, an independent sample of DPTs from 50 males and 50 females of known Chronological Age, between 10 and 16 years, were collected. TDSs for all developing permanent upper and lower teeth were scored using the 8 stage technique described by Demirjian (Fig. 1)^{9,11} In addition, the 3rd permanent molars in each quadrant were also assessed. Only the first half of the Demirjian method, the descriptions of TDSs⁹ are used in this paper. The numerical integration used by the Demirjian paper has not been used here.

2.5. Summary data for use with DAA

In addition to the TDSs for all TMTs, demographic data including the date of birth, date of radiograph, and gender for each subject, were entered into the database. Within the Microsoft Access Database it is possible to create a query to calculate the age of attainment of each TDS present in an individual subject. From these summary data, the mean age of attainment and standard error of each TDS was retrieved after the exportation of data into Microsoft Excel.

2.6. Meta-analysis for DAA

The mathematical technique of meta-analysis was used to provide an estimate of the Dental Age for a subject. This is achieved by calculating the weighted mean of TDSs in an individual, with each weight being proportional to the variation within the sample (standard deviation) and the number of each TDSs.¹⁶ A random effects model is used for the calculation and this incorporates the variation within the TDSs into the weighted value. The accuracy of the Dental Age Assessment was established by comparing the calculated DAA with the gold standard of Chronological Age using a Bland and Altman plot.¹⁸ This type of analysis is known as a method comparison study, which in this case measured the difference between Chronological Age and estimated Dental Age.

3. Statistical management of data

3.1. Reference data set

The database comprised a total of 5187 radiographs of which 520 between the ages of 11–15 years were added by the first investigator (PC). There were 1231 Caucasian subjects aged between 10 and 16 years old of which 671 were females and 560 males.



Fig. 2. Dental panoramic radiograph of worked example.

Queries were created within the database to identify the selected DPTs for the age range allowing the investigator (PC) to assess the TDS for each developing tooth present. The Chronological Age was calculated by using the date of birth and date of radiograph for each subject. Gender specific Summary Data was then produced for all TDSs as follows: number of subjects (n-tds); mean (x); standard deviation (sd); and standard error (se). The age of attainment for each TDS is normally distributed, enabling the assessor to determine the Dental Age from the numerical data produced.

3.2. Study sample

A Study sample was obtained to test the validity and accuracy of the method at the 13 year threshold. This comprised Caucasian subjects of which 50 were male and 50 were female. The subjects were randomly selected between the ages of 10–16 years from a separate archive of radiographs of known ethnicity (Fig. 2).

The TDSs¹¹ for all developing teeth were examined and recorded for each individual using the Demirjian TDS system (Fig. 1). For each study subject, a small table was completed comprising each TDS present, the mean age of the stage and the associated standard error (se). Stage H (closed root apex) is excluded for Dental Age calculations as stage H does not follow a normal distribution curve, hence is considered to be inaccurate.¹⁹ It is also claimed to be difficult to pin-point the exact time the root apex closes.^{20,21} The Dental Age of each subject was obtained by using the mathematical technique of meta-analysis as follows:

Step 1: After the TDSs were coded (Table 1), the data was entered into an Excel spreadsheet. A hyphen was used to show any poor quality images and if the apical end if the root canal is closed (stage H). Problems associated with missing teeth or poor quality DPT imaging can be solved by the substitution of the right maxillary and mandibular dentition. This is due to the symmetry in tooth development between the right and left side of the dentition^{22,23} (e.g.

Table 1
TDSs determined for each TMT for worked example.

Upper Teeth								
UL1	UL2	UL3	UL4	UL5	UL6	UL7	UL8	UR8
H	H	?	H	H	H	F	C	C
Lower Teeth								
LL1	LL2	LL3	LL4	LL5	LL6	LL7	LL8	LR8
H	H	G	H	G	H	F	A	A

The question mark denotes that the image is not clear. This tooth is excluded from the analysis.

UR7Gm can be used to substitute UL7Gm and Summary Data for UL7Gm would be used.) (Table 2)

Step 2: This patient specific data comprising the mean and standard error for each TDS present in an individual was transferred into STATA, a statistical package which was used to produce the estimated Dental Age as well as a Forest Plot (Fig. 3).

The Dental Age was assigned as follows²⁰:

1. for all developing teeth in the dentition and for each TDS present, the mean age for the age distribution is weighted.
2. the values produced were then combined to calculate the estimated mean age for that subject

The Forest Plot provides a visual representation of the spread of ages of attainment of TDSs within an individual. This is especially helpful as the size of the 'square' for each TDS gives an indication of the weighting attributed to each of the TDS present. The weighting is by sample size (n-tds) and standard error (se). The larger the sample size, the greater the weight attached and the larger the standard deviation (sd), the less weight is attached. The graph shows (Fig. 3):

1. The estimated mean age for each TDS
2. A 99% confidence interval for the mean population age
3. An overall mean estimate of the Dental Age for that subject

Step 3: The Dental Age was then compared for females and males separately with the gold standard of the Chronological Age. The method comparison technique by Bland and Altman¹⁸ was applied to the data derived to assess the Chronological and Dental Age as well as the student 't' test. This technique was applied to check the validity of the Dental Age Assessment that has been completed with a known technique of determining a subject's age, that is the Chronological Age derived from the date of birth.

3.3. Student t-tests

Paired t-tests are applied when the data are normally distributed or matched. Thus the t-test was used to compare the mean Chronological Age and the mean Dental Age. The p-value is "the probability of an observed result happening by chance under the null hypothesis".²⁴

Table 2
Summary Data for worked example.

Tooth morphology type (TMT)	Tooth morphology type (TMT) and stage (A–H)	Mean years (Years)	Standard error (se)
UL1	UL1H	–	–
UL2	UL2H	–	–
UL3	UL3?	–	–
UL4	UL4H	–	–
UL5	UL5H	–	–
UL6	UL6H	–	–
UL7	UL7F	11.48	0.31
UL8	UL8C	11.40	0.24
UR8	UR8C	11.50	0.24
LL1	LL1H	–	–
LL2	LL2H	–	–
LL3	LL3G	11.52	0.38
LL4	LL4H	–	–
LL5	LL5G	13.22	0.23
LL6	LL6H	–	–
LL7	LL7F	11.75	0.39
LL8	LL8A	10.04	0.15
LR8	LR8A	10.96	0.66

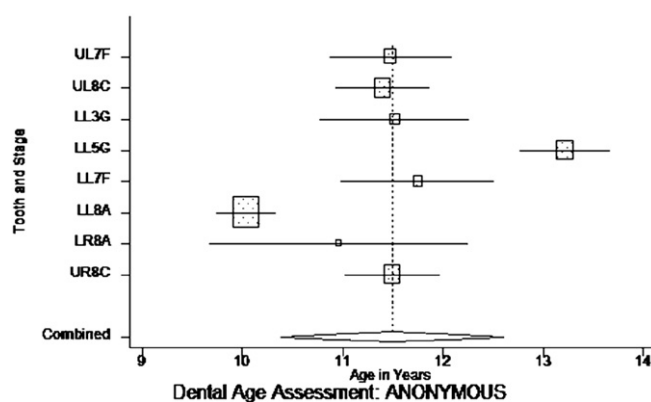


Fig. 3. Forest Plot for example subject.

4. Results

4.1. Reproducibility

The Kappa score for intra examiner reproducibility for the TDSs was 0.9135 which is an 'almost perfect' agreement. The inter examiner Kappa score was 0.8029. This agreement is rated as 'substantial'.¹⁷

4.2. Reference data set

There were 1231 Caucasian subjects aged between 10 and 16 years old of which 671 were females and 560 males.

4.3. Study sample

The validation sample consisted of 50 male subjects and 50 female subjects (Tables 3 and 4). For the males, the mean Chronological Age was 12.37 years, the standard deviation 1.36 and the 99% confidence interval for the population mean was between 11.86 years and 12.89 years. For the females, the mean Chronological Age was 13.09 years, the standard deviation 1.60 and the 99% confidence interval was between 12.49 years and 13.70 years (Table 5).

4.4. Dental age assessment: study sample and the accuracy of the dental age

The mean difference between the Chronological Age and Dental Age using the mathematical method of meta-analysis was –0.1 years (–1.2 months) for males and –0.05 years (–0.6 months) for females (Table 6).

4.5. Comparison of the estimated dental age and chronological age for subjects in the Caucasian population

The Bland and Altman method¹⁸ was used to assess the level of agreement between the Chronological Age and Dental Age. Figs. 4 and 5 show a good level of agreement.

4.6. Paired t-tests

The t-test performed for males has a p-value of 0.5043 and for females the p-value is 0.7565. These results indicate that there is no statistically significant difference between the Chronological Age and Dental Age for both male and female subjects.

Table 3
Study Sample Statistics for all 50 male subjects.

Case number	CA (years)	DA (years)	Diff in CA and DA (years)
1	11.01	12.64	-1.63
2	12.83	12.52	0.31
3	13.25	14.66	-1.41
4	12.99	13.13	-0.14
5	11.04	11.17	-0.13
6	13.21	12.30	0.91
7	13.61	13.81	-0.20
8	10.66	8.71	1.95
9	12.06	14.12	-2.06
10	11.66	11.49	0.17
11	15.41	15.47	-0.06
12	11.11	10.29	0.82
13	12.00	13.65	-1.65
14	15.58	16.00	-0.42
15	12.23	12.64	-0.41
16	11.36	10.54	0.82
17	11.47	13.01	-1.54
18	14.11	14.48	-0.37
19	13.29	14.45	-1.16
20	14.28	13.61	0.67
21	14.97	15.44	-0.47
22	11.03	12.06	-1.03
23	9.89	8.74	1.15
24	11.95	13.10	-1.15
25	12.03	11.45	0.58
26	13.03	14.43	-1.40
27	11.21	9.17	2.04
28	11.35	9.69	1.66
29	11.34	10.16	1.18
30	11.21	9.78	1.43
31	11.85	12.47	-0.62
32	11.95	11.69	0.26
33	11.79	11.98	-0.19
34	13.90	14.87	-0.97
35	12.74	12.23	0.51
36	13.03	14.43	-1.40
37	13.47	12.44	1.03
38	9.43	9.04	0.39
39	11.04	9.77	1.27
40	10.49	11.07	-0.58
41	12.08	11.69	0.39
42	11.12	10.28	0.84
43	13.17	13.99	-0.82
44	11.75	13.20	-1.45
45	12.62	14.22	-1.60
46	12.70	13.46	-0.76
47	13.46	14.26	-0.80
48	13.29	12.44	0.85
49	13.20	14.07	-0.87
50	14.47	13.46	1.01
Count (N)	50	50	50
Mean (x)	12.37	12.48	-0.10
Standard deviation (sd)	1.36	1.90	1.06

Table 4
Study Sample Statistics for all 50 female subjects.

Case number	CA (years)	DA (years)	Diff in CA and DA (years)
51	11.98	13.68	-1.70
52	11.85	12.86	-1.01
53	11.62	12.95	-1.33
54	14.56	14.78	-0.22
55	12.79	11.80	0.99
56	13.90	15.02	-1.12
57	14.69	14.15	0.54
58	12.07	12.12	-0.05
59	14.72	14.67	0.05
60	14.93	12.54	2.39
61	13.57	11.97	1.60
62	12.64	10.48	2.16
63	9.91	10.00	-0.09
64	15.05	12.04	3.01
65	10.19	11.86	-1.67
66	10.94	12.79	-1.85
67	11.31	11.51	-0.20
68	11.97	13.25	-1.28
69	12.19	13.27	-1.08
70	12.79	13.30	-0.51
71	12.65	13.65	-1.00
72	15.26	14.77	0.49
73	11.08	10.39	0.69
74	10.34	10.85	-0.51
75	13.28	12.92	0.36
76	10.41	9.76	0.65
77	13.35	14.78	-1.43
78	13.85	13.68	0.17
79	14.81	16.21	-1.40
80	13.68	14.52	-0.84
81	13.91	13.34	0.57
82	10.85	9.74	1.11
83	14.47	14.39	0.08
84	14.80	15.21	-0.41
85	15.07	15.18	-0.11
86	13.07	15.21	-2.14
87	15.11	12.91	2.20
88	11.15	10.80	0.35
89	14.79	15.44	-0.65
90	15.23	14.24	0.99
91	14.28	13.72	0.56
92	12.71	10.65	2.06
93	15.84	15.02	0.82
94	13.99	15.57	-1.58
95	14.58	14.67	-0.09
96	11.67	10.56	1.11
97	13.41	14.57	-1.16
98	13.46	14.69	-1.23
99	12.06	12.24	-0.18
100	11.70	12.48	-0.78
Count (N)	50	50	50
Mean (x)	13.09	13.14	-0.05
Standard deviation (sd)	1.60	1.73	1.21

5. Discussion

The purpose of this study was firstly to develop a Reference Data Set for Dental Age Assessment at the 13 year old threshold in Caucasian children. In addition, accuracy of estimated DAA at this threshold was compared with the gold standard of Chronological Age.

Tooth Development Stages have been used to estimate Dental Age in a Caucasian population. TDSs were recorded for all developing permanent maxillary and mandibular teeth on the left side plus all four permanent molars. The difference between the estimated DAA and the Chronological Age was within an average of one month.

The difference between the Chronological Age and Dental Age was not statistically significantly different. On average, this is relatively small (-1.2 months and -0.6 months difference for males

and females respectively). This method of Dental Age Assessment provides reliable estimations of age. For example, for immigration purposes; Immigration Law Court accepts estimates of age using these methods.

The use of the two-tailed *t*-test is justified as the data for the TDSs are all normally distributed. The results produced were 0.5043 and 0.7565 for males and females respectively, which

Table 5
Summary Data for all male and female subjects in the Study Sample.

Gender	Number of subjects (N)	Mean chronological age (years)	Standard deviation (sd)	Upper 99% confidence limit (years)	Lower 99% confidence limit (years)
Males	50	12.37	1.36	11.86	12.89
Females	50	13.09	1.60	12.49	13.70

Table 6

Mean difference between the Chronological Age and Dental Age using meta-analysis.

Gender	Number of subjects (N)	Mean difference (CA–DA in years)
Males	50	–0.10
Females	50	–0.05

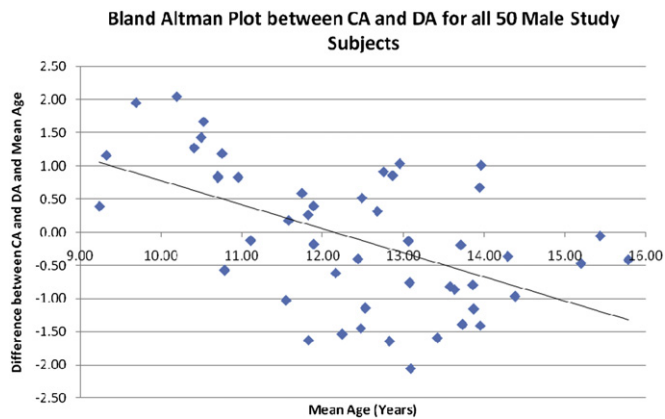


Fig. 4. Bland Altman Plot for males.

indicates there is no systematic difference or bias between the Chronological Age and Dental Age. This suggests a strong relationship between the mean Chronological Age and the mean Dental Age. In contrast to other studies, comparisons between males and females have not been made.

The Demirjian 8 stage system of scoring TDSs was used because it is straightforward and reproducible. It is also essential to include a Study Sample which is independent of the main Reference Data Set. The dates of birth of the 50 male and 50 female subjects were blinded to the investigator at the time of the assessment. The closeness of the Dental Age and Chronological Age were revealed to the investigator when the Bland Altman plot was constructed.

A further method that may provide useful data is the technique used to estimate the probability that a subject is above or below a predetermined threshold, for example, 13 years. This can be calculated from combining the probabilities of being under or over aged from each tooth that is used in meta-analysis. This method will be the subject of further communication.

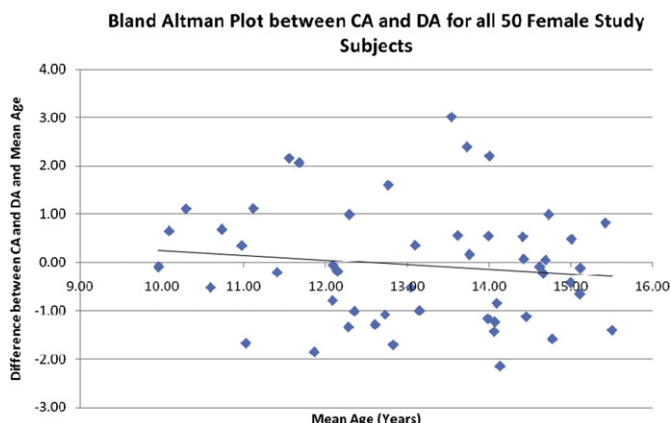


Fig. 5. Bland Altman Plot for females.

This work adds to the understanding of estimating the age of subjects of unknown date of birth, although ethnic and gender differences have not been specifically addressed in this study. The weighted average method has been demonstrated as a reliable technique of estimating Dental Age. This has also been shown at the 16 and 10 year threshold.^{16,25,26} The numerical data at the 13 year threshold provides a substantial degree of confidence for further work to be conducted using this method of assessment.

6. Conclusion

1. Reference Data for Dental Age Assessment (DAA) at the 13 year old threshold was established.
2. The 8 stages of Tooth Development described by Demirjian⁹ were extended to include all four third permanent molars.
3. The validity of the Dental Age Assessment (DAA) method was tested using a sample of Caucasian children at the 13 year threshold of known Chronological Age.
4. The mathematical technique of meta-analysis¹⁶ was used and results show:

The mean difference between the Chronological Age and Dental Age was –0.1 years (–1.2 months) for males and –0.05 years (–0.6 months) for females. The Dental Age Assessment for this study appears to underestimate the Chronological Age. The underestimation was greater in males (–0.1 years) than females (–0.05 years).

5. The differences between the Chronological Age and Dental Age were statistically significantly different. On average, this is relatively small (–1.2 months and –0.6 months difference).
6. Further work is required to reliably estimate the Age of Attainment of the Demirjian Tooth Development stages in different ethnic groups.

Conflict of interest statement

None declared.

Funding

None declared.

Ethical approval

Ethical approval was granted by the King's College Hospital NHS Trust (Reference number: 06/Q0703/54). To ensure the data complied with the Data Protection Legislation, the study was registered by The Data Protection Officer of King's College Hospital NHS Trust.

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